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The environmental footprint of an organic peri-urban orchard network

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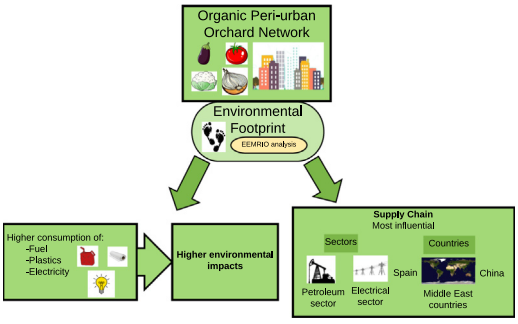
HIGHLIGHTS

- The Environmental Footprint of an organic peri-urban orchard network was assessed.
- Higher impacts were due to a higher consumption of fuel, plastics and electricity.
- Petroleum and electrical sector in Spain, China and Middle East countries were identified in the supply chain as the most influential.
- Favorable environmental impacts were obtained.

GRAPHICAL ABSTRACT



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ABSTRACT

Over the past years, the implementation of urban and peri-urban orchards in cities has increased and so has the environmental awareness regarding these systems. This study applied the environmental extended multi-regional input-output analysis to obtain the Environmental Footprint associated with an organic peri-urban orchard network in Spain. The total environmental impacts were calculated for seven organic peri-urban orchards identified as PUO1 to PUO7. PUO1, PUO4 and PUO6 presented the highest environmental impacts due to a higher consumption of (1) fuel, (2) plastics and (3) electricity in comparison to the other orchards. Approximately 70% of the overall impacts were indirect impacts generated in the supply chain. A more in-depth study of climate change impacts in the supply chain of the organic peri-urban orchard network revealed that the major hotspots were the sectors "extraction of crude petroleum" (29%) and "production of electricity by gas and coal" (31%) located in Spain, China and Middle East countries. The Environmental Footprint serves as a useful indicator to provide the environmental performance of an organic peri-urban orchard network and foster greener and more sustainable cities.

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1. Introduction

The world's population has experienced an extremely rapid growth. Over the past twelve years, there has been an addition of one billion people. It has been predicted that the total population will be between 8.4 and 8.7 billion in 2030 and between 9.4 and 10.2 billion in 2050 (UNPD, 2017). The increasing demographic and economic growth have led to an urban transition. The population has shifted from rural areas to cities. In 2016 it was reported that urban population

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represented approximately 54.5% and it has been estimated that by 2050 66% of the world's population will be urban (United Nations, 2016). Urbanization can have some positive impacts on economic growth. However, sustainable development can also be threatened by an unplanned urban growth. The uncontrolled urban expansion could entail the risk of destroying ecosystems, deforestation and contribute to climate change (United Nations, 2014). The issue of urban sustainability was first addressed in Rio with Agenda 21 and was followed by United Nations City Summit in Istanbul in 1996 (Deelstra and Girardet, 2001). Nowadays, it is a fact that cities exert high pressures on the environment and also generate a high amount of waste (European Commission, 2010).

One of the challenges presented by urbanization is to promote sustainable cities. In doing so, urban and peri-urban agriculture has been implemented as a way of integrating plant growth and animal breeding within and around cities (Duzí et al., 2017). This type of agriculture can be expressed in different forms and spatial structures, such as green roofs, hydroponic greenhouses, community and backyard gardens, school farms and food cooperatives (Kontothanasis, 2017). Research on different cities report that 500 ha are used in London to produce 8400 t of fruit and vegetables, in Berlin there are 80,000 local gardeners and in Paris, several experimental rooftop gardens have been opened testing the level of pollution generated to produce fruit and vegetables (Deelstra and Girardet, 2001; Grard et al., 2017; Petts, 2001).

In order to measure and communicate in a transparent way the environmental pressures of products and organizations, the Environmental Footprint (EF) was proposed by the European Commission (European Commission, 2010). By modeling fourteen impact categories, which include the emissions, wastes, energy and material flows, the environmental performance is obtained (He et al., 2017). Kulak et al. (2013) studied the possibility of reducing the global warming potential with urban agriculture. By integrating this type of agriculture in urban areas, together with a specific selection of crops and techniques, greenhouse gas emissions could be reduced. However, greenhouse gas emissions only provide a limited perspective as it only focuses on a single environmental impact. On the other hand, Rothwell et al. (2016) investigated a range of environmental indicators, such as global warming potential, land use, water use and eutrophication, to compare the trade-offs of local peri-urban production of lettuce with field production through life cycle assessment. This research proved the importance of emphasizing in other impact categories and showed the potential of peri-urban horticulture to improve the environment. Following this path, it was also tested the efficacy of urban agriculture as an environmentally superior production over conventional agriculture. However, environmental impacts may vary depending on the region. Goldstein et al. (2016) found that the overall environmental reduction by urban agriculture appeared to be limited in northern cities.

In Spain, urban and peri-urban agriculture has experienced an increasing interest over the past years. In 2000, 148,542 m^2 of the urban area was dedicated to agriculture in this country, whereas in 2015 the area highly increased to 2,190,233 m^2 (Ballesteros, 2014). A growing interest in urban and peri-urban agriculture has emerged prompted by the environmental deterioration of cities. This type of agriculture appears as one of the possible solutions to cities' environmental issues, such as the increasing levels of pollution and waste disposal (Mougeot, 2006).

In order to be able to confirm the benefits this agriculture claims, specific tools are required. The Environmental Extended Multi-Regional Input-Output (EEMRIO) analysis is a well-known technique applied to obtain the footprints of nations, sub-national entities, socio-economic groups and organizations or companies (Wiedmann, 2009). By applying this method, the incompleteness presented by the process-based method due to the truncation effect is overcome (Suh et al., 2006). It was applied by Weber and Matthews (2008) to estimate the climate impacts of local food considering all the environmental emissions along the entire supply chain and concluded that buying local food could reduce a 4% the overall greenhouse emissions.

Within the environmental impacts of urban and peri-urban agriculture found in the existing literature, these are usually restricted to carbon emissions. In this paper, we propose the EF as a complete indicator to evaluate the environmental performance of this type of agriculture. In addition, while previous investigations have limited their boundaries to study the peri-urban systems, we have also included all upstream impacts by using the EEMRIO analysis. Our contention presented here is that the calculation of the EF could serve as evidence to support the implementation of more peri-urban orchards. Furthermore, the EEMRIO analysis could provide a comprehensive assessment assisting consumers and policy-makers by identifying areas for improvement of their environmental performance. In order to do so, our objectives were to: (1) assess the EF of a network of organic peri-urban orchards, (2) Identify the carbon emission hotspots with regards to the sectors and countries involved in the supply chain, and (3) establish the implications of urban and peri-urban agriculture.

2. Material and methods

2.1. Organic peri-urban orchard network

The organic peri-urban orchard network studied in this research consists of seven peri-urban orchards located in the Spanish city of Zaragoza (Fig. 1 and Table 1). They are located near the Ebro River, where the soil is classified as Haplic Gypsisol (GY) and the climate is characterized as continental Mediterranean climate (IUSS Working Group WRB, 2014). With regards to the management practices, the orchard's areas were managed according to organic agriculture practices (FAO, 2015). In general, the agronomic field operations included plowing, fertilizing, sowing, mulching, irrigation carried out by drip irrigation and harvesting (Fig. 2). The specific characteristics of an organic management included the substitution of synthetic chemicals by natural fertilizers, such as manure and other organic composted substances, and the prevention of pest and disease by weeding and using natural pesticides.

2.2. Methodology

In order to calculate the Environmental Footprint (EF), three steps were followed. In the first place, the inventory phase consisted of collecting all the necessary information related to the orchards' activities (Fig. 3). The municipal government was in charge of requesting and facilitating the economic inputs for the assessment. The information required for the calculation of the total impacts is expressed in monetary terms and includes the accounting records of the goods and services needed for the vegetable production. Capital expenditure has been considered as direct expenses (executed in 2016). Consequently, no amortization period has been considered. In the same way, depreciation costs and amortization expenses related to investments from previous years have not been included in the study. The boundaries of the system refer to the organizational and operational boundaries which include the expenditure involved in energy consumption, water consumption, fuel consumption and other expenses incurred to obtain the total production of each orchard. They were then allocated in the 163 sectors included in the multi-regional input-output database of EXIOBASE (Wood et al., 2015). The soil and crop preparation, the harvesting and transport to consumer phases have all been considered as the production phase comprised in the orchard network.

In the second phase, the calculation of the EF was carried out. Applying an EEMRIO analysis, the total impacts of fourteen impact categories can be obtained using the expenditure as inputs for this method. The impact categories studied were climate change, ozone depletion, human toxicity cancer effects, human toxicity non-cancer effects, particulate matter, photochemical oxidation, acidification, eutrophication-

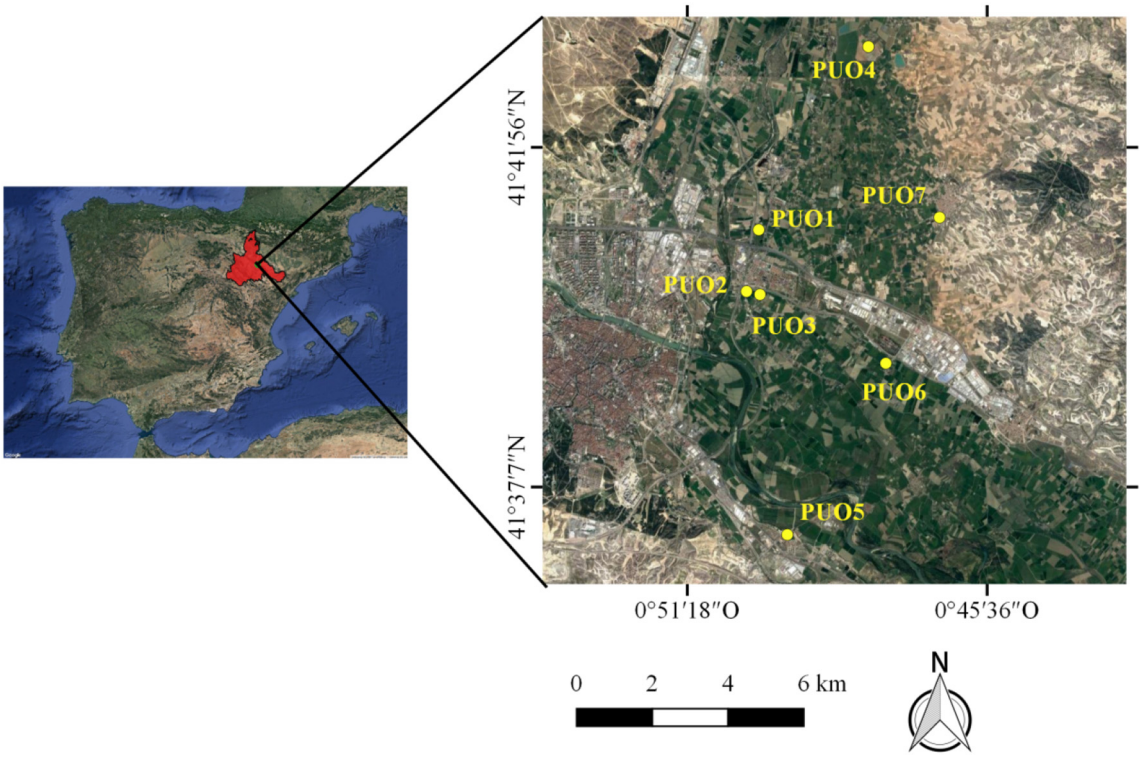

Fig. 1. Location of the organic peri-urban orchards.

freshwater, eutrophication- terrestrial, eutrophication- marine, fresh water ecotoxicity, land use, resource depletion-water, and resource depletion-mineral & fossil.

The third and last step was the analysis phase, where the total impacts were evaluated to study the general environmental performance of the peri-urban systems. In addition, one of the advantages presented by this method is its capability to track the countries and sectors involved in the supply chain of an organization or system (Wiedmann et al., 2011). As the project wanted to emphasize on the carbon emissions of the organic peri-urban orchard network, this method was applied to track the origin of these emissions through its entire supply chain.

In this study, the EEMRIO analysis is applied for the calculation of the EF. It is a top-down economic technique that allows the modeling of country and sectors interdependencies (Schaffartzik et al., 2014; Turner et al., 2007). This well-known method has been applied in previous investigations to obtain the environmental performance of organizations and systems (Huang et al., 2009; Martinez et al., 2018; Wood and Lenzen, 2003). The basic expression of the environmental extended multi-region input-output method is:

$$\boldsymbol{E} = \boldsymbol{e}\,(\boldsymbol{I}-\boldsymbol{A})^{-1}\boldsymbol{y} \tag{1}$$

where **E** is the total environmental impact matrix. Term ***e*** is the environmental intervention matrix, which is a diagonalized matrix containing the environmental burdens per monetary unit of each sector. In this study, ***e*** is referred to the fourteen environmental impact categories calculated, such as climate change, ozone depletion, human toxicity cancer effects, human toxicity non-cancer effects, particulate matter, photochemical oxidation, acidification, eutrophication- freshwater, eutrophication- terrestrial, eutrophication- marine, fresh water ecotoxicity, land use, resource depletion-water, and resource depletion-mineral & fossil. ***I*** is the identity matrix and ***A*** is the technical coefficient matrix. The expression $(\boldsymbol{I}\text{-}\boldsymbol{A})^{-1}$ is known as the Leontief inverse matrix and consists of multipliers that depict the production of each industry in order to meet the final demand (***y***), which in this case corresponds to the peri-urban orchard network expenditure. By summing the columns of matrix **E** the environmental responsibility is allocated to the consumers, also known as consumption-based accounting (Zafrilla et al., 2014). Further details regarding the input-output model for environmental impacts can be found in Miller and Blair (2009).

Table 1
Orchards' characteristics included in the organic peri-urban orchard network.

Organic Peri-urban orchard	Production (kg)	Area (m^2)	Total expenditure (€)
PUO1	18,140	32,000	7548
PUO2	5890	6000	3480
PUO3	7445	n.s.	2142
PUO4	27,190	64,000	22,137
PUO5	2834	1530	1062
PUO6	17,545	30,000	6075
PUO7	3190	11,000	1751

n.s.: Not specified.

The database used for this investigation was the EXIOBASE 2.3 multi-regional input-output tables from 2007 as it had been reported its high level of sectorial detail and environmental information compared to other databases (Wood et al., 2015). The combination of the environmental extensions across 43 countries and 5 rest-of-the-world regions consisting of 163 industrial sectors each, provides a highly detailed environmental assessment of the organic peri-urban orchard network and enables a more in-depth study of its embodied impacts worldwide.

A structural path analysis was then carried out to obtain the direct and indirect impacts embodied in the peri-urban organic orchard network. This decomposition approach has been described in the literature (de la Rua and Lechon, 2016; Wood and Lenzen, 2003; Zafrilla et al., 2014) and consists of decomposing the Leontief inverse (L) in a power series expansion as follows:

$$\boldsymbol{L} = (\boldsymbol{I}-\boldsymbol{A})^{-1} = \left(\boldsymbol{I} + \boldsymbol{A} + \boldsymbol{A^2} + \boldsymbol{A^3} + \ldots + \boldsymbol{A^n}\right) \tag{2}$$

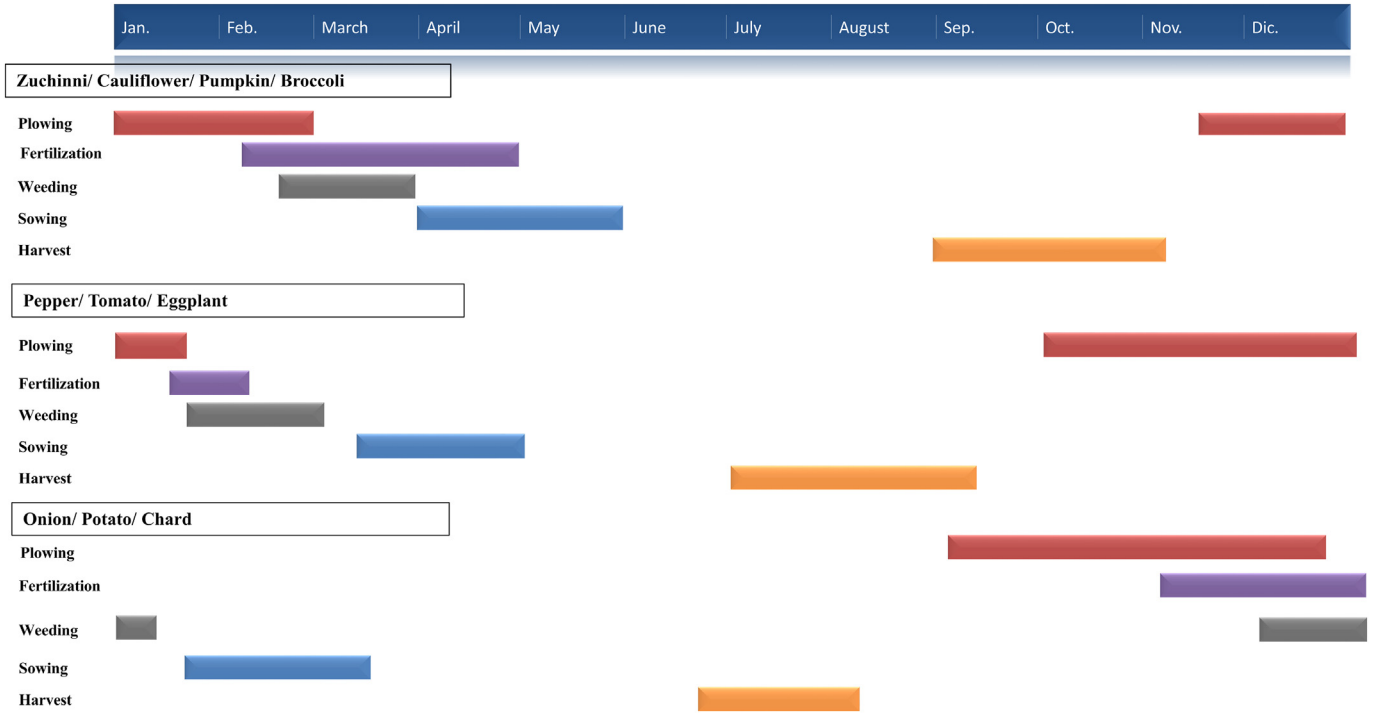

Fig. 2. Management practices in the organic peri-urban orchard network: Periods in which operations were carried out for the main crops.

Eqs. (3) and (4) show the direct multipliers (***LD***) and indirect multipliers (***LI***). These multipliers are used with the corresponding environmental matrices (***e***) to calculate the direct and indirect effects of each impact category.

$$\boldsymbol{LD} = (\boldsymbol{I}) \tag{3}$$

$$\boldsymbol{LI} = \left(\boldsymbol{A} + \boldsymbol{A}^{\boldsymbol{2}} + \boldsymbol{A}^{\boldsymbol{3}} + \ldots + \boldsymbol{A}^{\boldsymbol{n}}\right) \tag{4}$$

3. Results

3.1. Environmental impact categories

The total impacts of the seven peri-urban orchards were calculated applying the EEMRIO analysis. Fig. 4 shows the impacts generated by the orchards in each impact category. For climate change, an average value of 8.8E+3 $kgCO_2$ eq was obtained for this network of orchards. On the other hand, if considered as a total, the overall emissions were 61.9E+3 $kgCO_2$ eq. It was found that PUO4 was the most polluting orchard in terms of carbon emissions followed by PUO6, with 2.8E +4 $kgCO_2$ eq and 1.3E+4 $kgCO_2$ eq, respectively. These two orchards were responsible for raising the emissions of this network. In fact, without considering PUO4 and PUO6, climate change is reduced a 53%. In addition, the direct and indirect impacts were calculated for each impact category. Direct emissions for climate change accounted for 31% of the overall impact, whereas the gross emissions were embedded in the indirect impacts. On the other hand, to be able to associate the emissions generated with the production achieved, the kg of CO_2 eq per kg of total production in each orchard was also calculated (Table 2). The same trend was observed for the emissions per functional unit of production as with the total impact. PUO4 and PUO6 emitted the highest impacts per kg of production, therefore, even though these orchards achieved

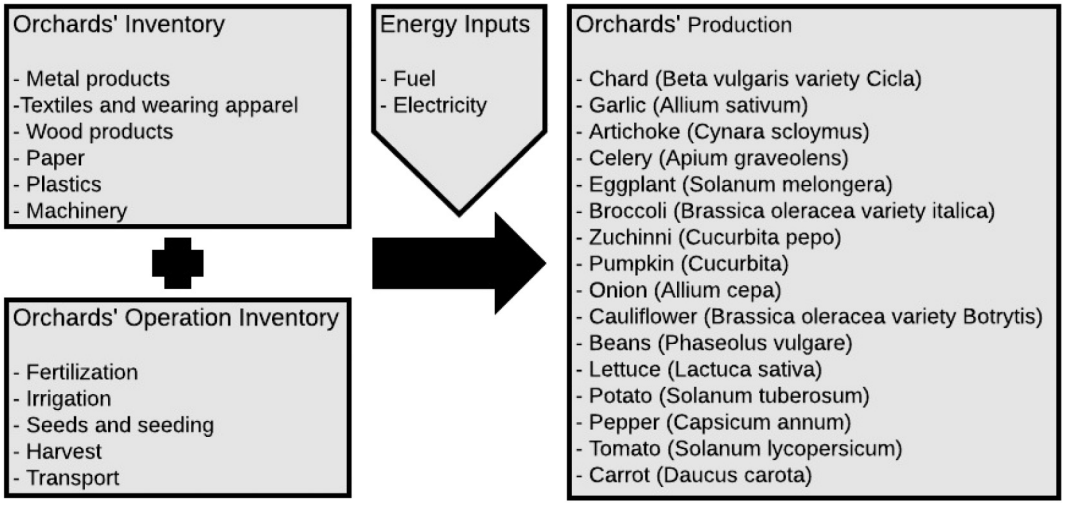

Fig. 3. Inventory inputs of the organic peri-urban orchard network.

the highest production, they were also identified as the most polluting, contributing a 23% and 15% to the total climate change impact of the orchard network.

In relation to ozone depletion, 6.1 kg CFC–11 eq was the average value of the peri-urban orchards and 42.8 kg CFC–11 eq the total impact of the seven orchards. The main contributor in this impact category was PUO4, which contributed a 55% to the total impact. However, unlike climate change, PUO1 and PUO6 achieved similar ozone loss, with 6.24 kg CFC–11 eq and 6.23 kg CFC–11 eq, respectively (Fig. 4). Comparing the origin of the impacts, it was seen the low contribution of the direct impacts with respect to the indirect ones, which were a 99% (Fig. 5). When analyzing the impacts from the production point of view, it has to be highlighted that PUO4 and PUO7 are the orchards with higher impacts, meaning that for each kg of production, PUO4 and PUO7 generate more ozone loss than the rest of orchards.

Human health is another indicator of great importance in peri-urban agriculture. In the orchard network studied, human toxicity cancer effects and non-cancer effects mean values were 1.6E−5 CTUh and 1.2E−3 kg CTUh, respectively. PUO4 once again stands out as the dominant orchard in these categories, representing a 50% in both categories of the total impacts, which are 1.1E−4 CTUh for cancer effects and 8.5E−3 CTUh for non-cancer effects (Fig. 4). From Fig. 5, it can be observed that the overall direct contribution to human toxicity of these orchards is really low (2%). 98% of the human risk impact is embodied in the supply chain as indirect impacts. In the same way as with ozone depletion, the higher impacts were spotted in PUO4 and PUO1, whilst PUO4 and PUO7 were the main contributors per functional unit of production with 2.1E−9 CTUh and 1.5E−9 CTUh for cancer effects and 1.6E−7 CTUh and 1.1E−7 CTUh for non-cancer effects (Table 2).

For acidification, the average value calculated was 46.8 molc H+ eq and the total impact for the seven orchards was 327.6 molc H+ eq. On the other hand, for ecotoxicity freshwater, the average value calculated was 858.2 CTUe and the total impact 6007.5 CTUe. PUO4 as the orchard with highest values for both indicators. However, for acidification, PUO6 was the second with highest values representing a 26%, while for ecotoxicity freshwater PUO1 represents 16.5% and is the second main orchard (Fig. 4). Comparing the direct and indirect impacts, ecotoxicity freshwater presents similar results as ozone loss, with low direct impacts, whereas, acidification's direct impacts resulted in the second highest of the fourteen impact categories, with a 19%. Nevertheless,

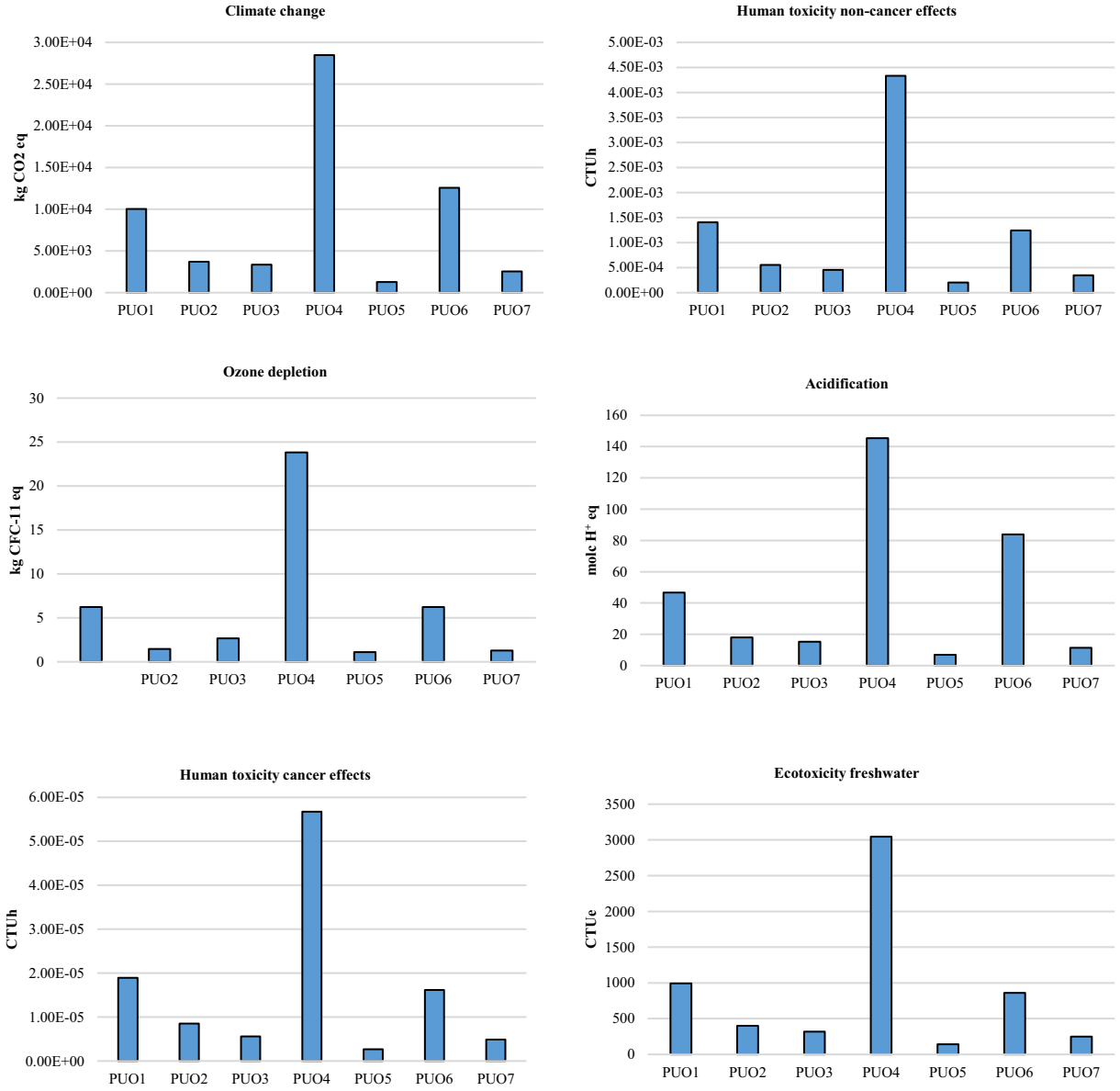

Fig. 4. Environmental impacts results for the seven organic peri-urban orchards according to the fourteen impact categories.

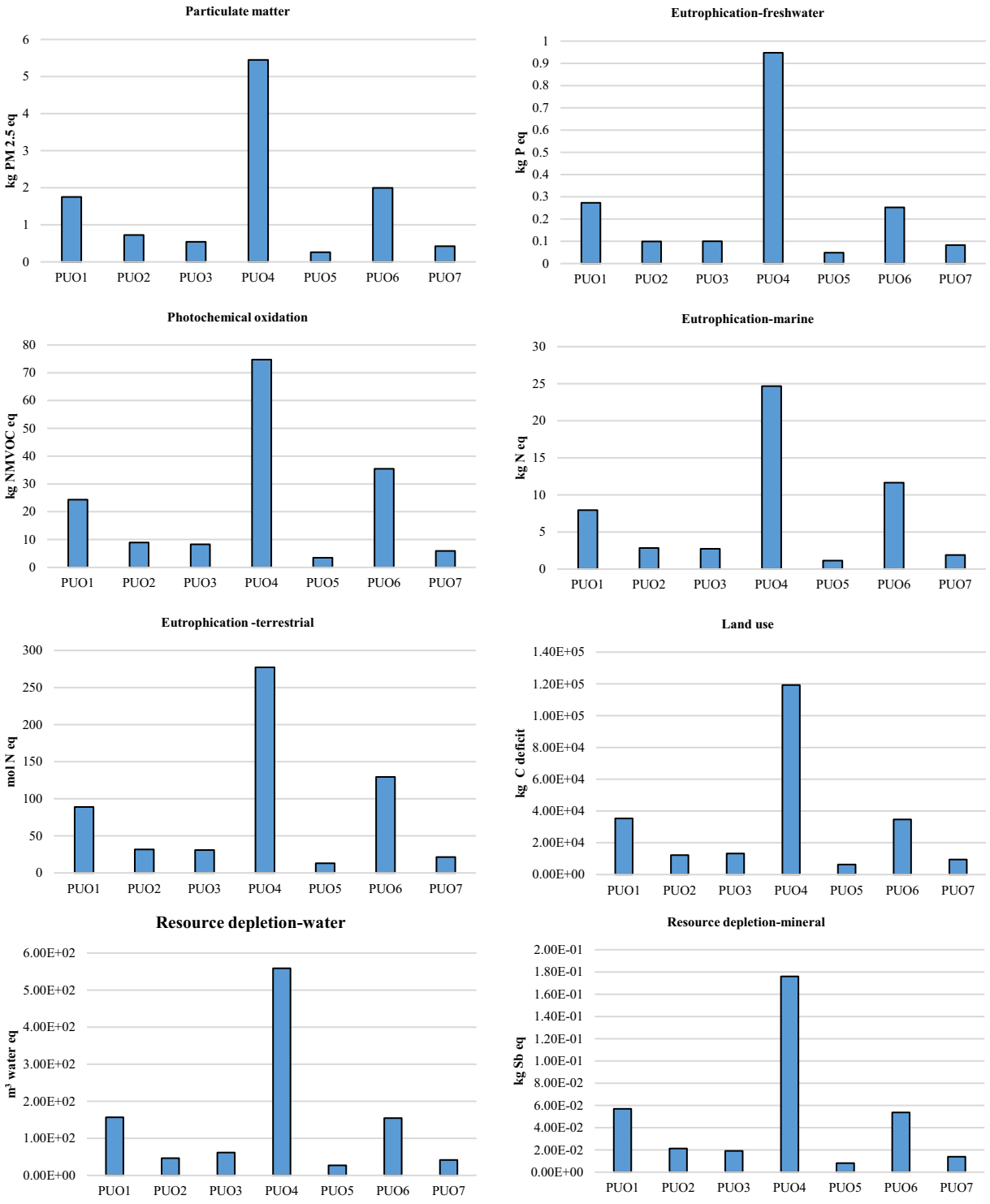

Fig. 4 (*continued*).

indirect impacts remain as the dominant contributors. In the case of molc H+ eq/kg and CTUe/kg, PUO4 and PUO7 were also found to exhibit the highest impacts related to acidification and ecotoxicity freshwater. It is interesting to point out that PUO6 and PUO1, which seemed to have a high acidifying and ecotoxic effect, when compared to their production, they are the second least polluting representing a 20% and 12%, respectively.

With regard to particulate matter, 1.6 kg PM2.5 eq and 11.1 kg PM2.5 eq were the average and total impact, respectively. For photochemical oxidation, those values were 23 kg NMVOC eq and 161.2 kg NMVOC eq, respectively. The same pattern was found for both indicators regarding the overall impacts of each orchard. As observed in the other impact categories, PUO4 had the highest values and represented a 49% and 46% of the total impact of particulate matter and photochemical oxidation, respectively. The next orchard with highest impacts was PUO6 with an impact of 2 kg PM2.5 eq for particulate matter and 35.5 kg NMVOC eq for photochemical oxidation (Fig. 4). Contributions of a 10% in acidification and 15% in photochemical

Table 2
Environmental impacts per unit of production (kg) for the seven organic peri-urban orchards.

Impact category	Unit	Orchard						
		PUO1	PUO2	PUO3	PUO4	PUO5	PUO6	PUO7
Climate change	kg CO2 eq/kg	5.53E−01	6.28E−01	4.50E−01	1.05E+00	4.46E−01	7.17E−01	7.98E−01
Ozone depletion	kg CFC-11 eq/kg	3.44E−04	2.46E−04	3.58E−04	8.76E−04	3.92E−04	3.55E−04	3.99E−04
Human toxicity cancer	CTUh/kg	1.04E−09	1.45E−09	7.48E−10	2.09E−09	9.51E−10	9.20E−10	1.54E−09
Human toxicity non-cancer	CTUh/kg	7.74E−08	9.44E−08	6.13E−08	1.59E−07	7.14E−08	7.08E−08	1.09E−07
Acidification	molc H+ eq/kg	2.57E−03	3.07E−03	2.06E−03	5.35E−03	2.44E−03	4.78E−03	3.56E−03
Particulate matter	kg PM2.5 eq/kg	9.65E−05	1.23E−04	7.25E−05	2.00E−04	9.18E−05	1.14E−04	1.32E−04
Fresh water ecotoxicity	CTUe/kg	5.47E−02	6.78E−02	4.29E−02	1.12E−01	5.05E−02	4.90E−02	7.84E−02
Photochemical oxidation	kg NMVOC eq/kg	1.34E−03	1.51E−03	1.11E−03	2.75E−03	1.22E−03	2.02E−03	1.86E−03
Eutrophication- terrestrial	molc N eq/kg	4.90E−03	5.35E−03	4.13E−03	1.02E−02	4.55E−03	7.38E−03	6.67E−03
Eutrophication- freshwater	kg P eq/kg	1.50E−05	1.68E−05	1.34E−05	3.48E−05	1.71E−05	1.44E−05	2.59E−05
Eutrophication- marine	kg N eq/kg	4.37E−04	4.81E−04	3.67E−04	9.07E−04	4.05E−04	6.63E−04	5.97E−04
Land use	kg C deficit/kg	1.95E+00	2.07E+00	1.77E+00	4.39E+00	2.25E+00	1.98E+00	2.97E+00
Resource depletion-water	m^3/kg	8.65E−03	7.92E−03	8.29E−03	2.06E−02	9.53E−03	8.81E−03	1.30E−02
Resource depletion- mineral, fossil	kg Sb eq/kg	3.13E−06	3.62E−06	2.58E−06	6.47E−06	2.89E−06	3.06E−06	4.37E−06

oxidation were found for direct impacts, being higher the indirect impacts located along the supply chain. The identification of the most contaminating orchards per kg of production in relation to both impact categories revealed that PUO4 and PUO7 were also the dominant orchards (Table 2).

The indicator eutrophication can be classified according to terrestrial, freshwater and marine. Following this order, the average values were 84.6 molc N eq, 2.5E−1 kg P eq and 7.5 kg N eq. In relation to the total impacts of the orchard network, the values calculated were 592 molc N eq, 1.8 kg P eq and 52.8 kg N eq for terrestrial, freshwater and marine, respectively (Fig. 4). Eutrophication terrestrial and marine present similarities according to the location of the impacts. PUO4 and PUO6 present the highest impacts, while for eutrophication freshwater PUO1 exhibited the second highest impact. In a similar way as photochemical oxidation, the 85% of the impacts of these three categories have their origin in the supply chain, remaining a low percentage attributable to direct impacts. On the other hand, eutrophication terrestrial and freshwater present similar contributions per kg of production of PUO4 and PUO7, with a 39% and 44%, respectively, and being these two orchards the most contaminating. In relation to eutrophication marine, the first two most polluting orchards contributed a 41% to the total impact per kg of production, but instead of PUO7, for this category PUO6 was the second most contaminating orchard.

Land use average value was 3.3E + 4 kg C deficit and the total 2.3E + 5 kg C deficit. PUO4 was a 72% higher than the average value, followed by PUO1 and PUO6 with values of 3.5E + 4 kg C deficit and 3.4E + 4 kg C deficit (Fig. 4). This impact was identified to have the most direct impacts associated with this orchard network. The embodied impacts in the supply chain were slightly higher than the direct ones, being 54% and 46%, respectively (Fig. 5). From the production point of view, PUO4 and PUO7 presented the highest impacts with 2.1E–2 kg C deficit/kg and 1.3E–2 kg C deficit/kg (Table 2). Not considering this two orchards, the total impact per kg of the other five orchards is reduced a 42%. This evidences that both orchards impose higher impacts on biodiversity, life support functions and potential future uses of the land than the rest of the orchards included in the network.

Finally, resource depletion is divided in water depletion and mineral depletion. The average values for water and mineral depletion were 149.6 m^3 and 5 kg Sb eq, respectively. On the other hand, the network of orchards exhibited a total of 1047 m^3 for water depletion and 3.5E−1 kg Sb eq for mineral depletion. As it was observed for the rest of the impact categories, PUO4 had the highest values and PUO1 and PUO6 the next highest impacts (Fig. 4). Water and mineral resources seem to be well managed, as the direct impacts only account for 2%, while care has to be put on the supply chain where 98% of the impacts are embedded. Looking at the production perspective too, in this categories the two orchards PUO4 and PUO6, identified for having high overall impacts, were also found to have high impacts per kg of production (Table 2). Both orchards added up to a total of 2.9E−2 m^3/kg and 9.5E−6 kg Sb eq, which represent more than 36% of the total orchard network.

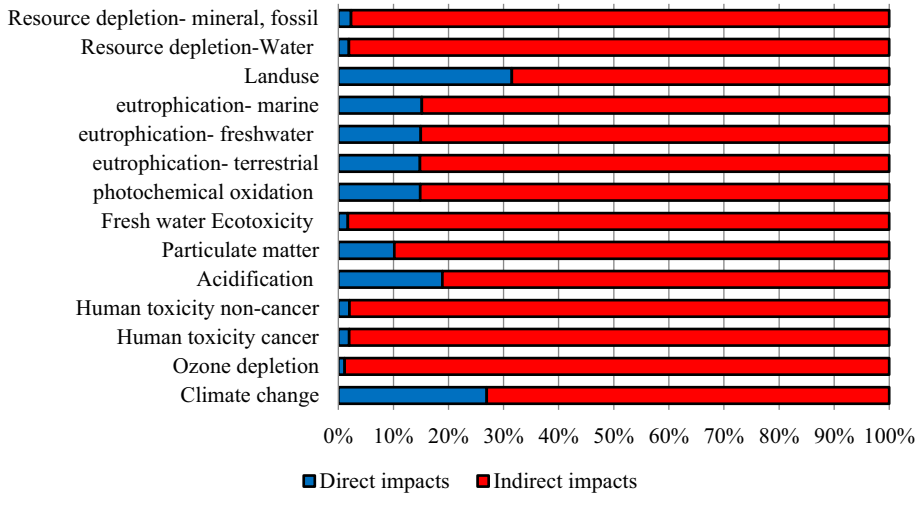

Fig. 5. Direct and indirect impacts distribution per impact category for the organic peri-urban orchard network.

3.2. Linkages of climate change in the organic peri-urban orchard network

The environmental best management practices can be extended to including strategic supply chain management. Addressing the sources of environmental impacts in supply chains should also be part of the assessment of a product's environmental performance. For that reason, a more in-depth study of the climate change impact was carried out.

EEMRIO method enables the assessment of the environmental impacts embodied in trade between sectors from different nations (Kitzes, 2013). The circos chart (Fig. 6) is a diagram that represents the environmental links between sectors and countries generating the impacts caused by the consumption of the different inputs of the orchard network. The color and size of the flows are useful in order to spot which sector and country are generating the highest impacts involved in the trade. It can be seen the high density of flows representing sectors and regions involved in the organic network of orchards studied. The explanation is that the process of peri-urban food production requires multiple goods and services.

It was highlighted that the three most influential sectors were "Extraction of crude petroleum", "production of electricity by gas" and "production of electricity by coal", contributing a 22%, 17% and 9% to the total emissions, respectively. Most of the emissions registered in the sector "extraction of crude petroleum" had their origin in Russia, while for the sectors "production of electricity by gas and coal" the dominant country was Spain. Taking into consideration the whole orchard system, the main polluting regions identified were Spain (31%), Middle East countries (14%) and China (10%). The rest of the countries have been found to contribute significantly less (44%) to the overall carbon emissions of these orchards than the above-mentioned countries.

To sum up, it is worth noting that the direct emissions are lower than the indirect ones, 31% and 69%, respectively. The direct emissions of this orchard network, in other words, the Spanish domestic emissions, were mainly generated by the sector "production of electricity by coal" and "production of electricity by gas". On the other hand, the indirect emissions, which are the ones in the supply chain, are located in the activity sector "extraction of crude petroleum".

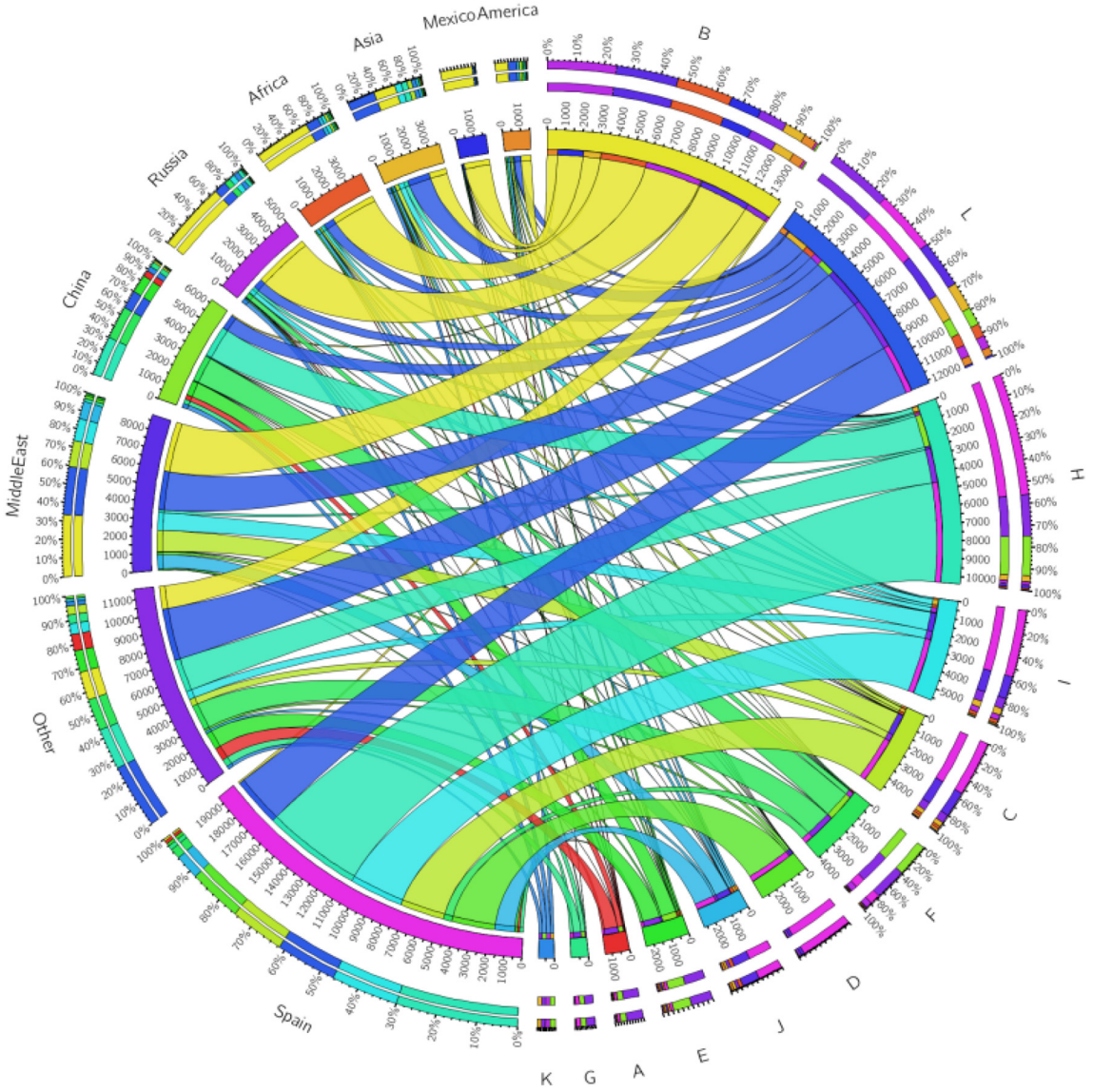

Fig. 6. Climate change linkages ($kgCO_2$ eq) by sectors and countries involved in the organic peri-urban orchard network. Sectors: A. Mining of coal and lignite; B. Extraction of crude petroleum; *C. petroleum* Refinery; D. Plastics; E. Chemicals; F. Manufacture of basic iron and steel; G. *Re*-processing of secondary steel; H. Production of electricity by coal; I. Production of electricity by gas; J. Production of electricity by petroleum; K. Steam and hot water supply; L. Other sectors. Countries: Spain; China; Middle East countries; Russia; Africa; Asia (Asian countries except for China); Mexico; America (North and South American countries except Mexico) and Others (rest of the world).

4. Discussion

4.1. Organic peri-urban orchard network environmental performance

The seven orchards were studied under the same environmental conditions, therefore, the differences were ruled by the management practices. Among the seven orchards analyzed, PUO1, PUO4 and PUO6 were found to have the highest environmental impacts. Such high impacts were due to a higher consumption of (1) fuel, (2) plastics and (3) electricity in comparison to the other orchards. To improve the environmental performance of these orchards, the machinery could be updated, adding more efficient equipment (Saidur et al., 2012). Additionally, the use of clean sources of energy could also reduce the overall impacts (Mehdi and Slim, 2017). Plastics were also used for the agriculture practice of mulching. Despite its benefits of conserving soil's moisture, increasing crop yield, etc., it can be highly pollutant depending on the origin of the plastic (Alam et al., 2018). In order to be able to apply this technique in a more sustainable way, natural mulches or biodegradable and photodegradable plastic mulches could be used (de Vargas Mores et al., 2018; Kasirajan and Ngouajio, 2012).

When analyzing the management practices, supply chain management can also play an essential role (Thorlakson et al., 2018). It has to be noted that the majority of the impacts come from indirect impacts from the supply chain (Ivanova et al., 2016). One of the most effective ways to promote greener supply chains is identifying the origin of the impacts (Acquaye et al., 2017). In the case of this orchard network, the study of its supply chain regarding the category climate change identified the sectors "extraction of crude petroleum" and "production of electricity by gas and coal" as two of the most influencing industrial sectors. A strategic action plan could then be shaped to reduce carbon emissions. For example, applying renewable energies, such as wind and solar energy, could reduce carbon emissions by 90%. In addition, the intensity of a sector may vary depending on the country of origin. Examining the multipliers of both countries for the electrical and petroleum sectors, it is seen that Spain's multipliers are a 73% and 19% lower than China's, respectively.

4.2. Comparing studies

The results presented fourteen impact categories related to seven organic peri-urban orchards. In relation to the literature, the most studied impact category in agriculture is climate change (Carlson et al., 2017; Clavreul et al., 2017; Huang et al., 2017). Comparing the carbon emissions obtained per unit of production in our study to the generated by a conventional food supply, it is seen that the impacts of all the crops studied are higher than the ones investigated here (Kulak et al., 2013).This is mainly due to management conditions. Conventional production can occur in heated greenhouses to achieve higher yields, with the downside of using large quantities of energy (Hatirli et al., 2006). In addition, when compared to the results of the community farm studied in London, PUO1, PUO3 and PUO5 presented a better carbon performance for beans (autumn), strawberry (outdoor) and tomatoes. Even the most polluting orchard (PUO4) results were a 16% lower than the impacts obtained by this community farm for strawberry (polytunnel). A key factor favoring these results was choosing better-suited crops. In this case for the same environmental impacts, higher crop yields led to a lower environmental impact per unit of production.

On the other hand, Rothwell et al. (2016) presented the environmental impacts for different lettuce farms. In this case, carbon emissions of lettuce production were higher for the low tech hydroponic farm, open field and high tech greenhouse than the emissions registered for PUO1, PUO3 and PUO5. The highest climate change impact was obtained for the low tech hydroponic farm, only exceeded by PUO4, being a 14% higher. It was the high tech greenhouse with solar energy the farm which obtained the lowest carbon emissions, approximately 0.3 kg CO_2 eq/kg, outperforming the peri-urban orchards in this study. These findings were expected as this farm used a renewable source of energy, which is less polluting and considered green. However, when focusing on water use, the values for all of the seven orchards were lower than the lettuce farms. This could be due to the fact that this network had installed a new irrigation system, optimizing the water dosing.

On another study carried out by Goldstein et al. (2016) analyzing the environmental performance of lettuce and tomatoes in six urban farms, several indicators were considered. For freshwater ecotoxicity, in general, tomato exhibited better performance than lettuce and comparing our orchards, they had lower values than these urban farms. The worst case in our network was found in PUO4 and had a value 44% lower than the best urban farm. With respect to eutrophication marine, only PUO1, PUO3 and PUO5 showed better results than two urban farms with tomato and for lettuce, our results and the urban farms are quite similar. Land use was also analyzed in the previously mentioned study. This indicator was higher for lettuce than for tomato, noting also that urban farms had worse results than the conventional farm in both crops. In comparison to these results, our orchards had lower values with the exception of PUO4 that, on average, was a 20% higher than the urban farms with tomato. Finally, with regards to resource depletion, it was also found out that our results were more favorable than the obtained for the urban farms assessed with both crops. In general, the orchards presented in this paper exhibited satisfactory results in comparison to other urban farms. Low values in some indicators, such as freshwater ecotoxicity, eutrophication marine and resource depletion, could be associated to the fact that these orchards follow an organic agriculture, meaning fewer fertilizers, chemicals and sustainable practices are applied for food production.

Not only studies concerning urban farms should be included in the comparison, but comparing organic production systems could also be interesting to assess the environmental performance of the orchard network. The records of organic apple orchards were collected to assess nine impact categories (Goossens et al., 2017). Comparing this investigation with ours, there are differences in the environmental performance depending on the indicator considered. The Spanish orchards in this paper are more sustainable than the apple ones from the point of view of human toxicity cancer effects, eutrophication terrestrial, freshwater ecotoxicity and mineral depletion. Nevertheless, in the categories of climate change, eutrophication freshwater and marine, land use and water depletion, the seven organic orchards exhibited higher impacts. A possible explanation to the obtained findings could be due to the difference in cultivation systems. While the apple orchards are a monoculture, the orchards in Spain are polyculture. Polyculture systems improve some impact categories, such as resource depletion because planting the different crops every year depletes the nutrients in the soil at a slower rate than monocultures (Simmons et al., 2011). In contrast, planting the same crop could lead to the optimization of inputs because the plant requirements, harvesting and growing operations are the same across the entire farmland. For this reason, some indicators such as the use of water and climate change, appear to be lower.

It is worth mentioning that the agricultural practices influence the environmental impacts of each system, but the type of crop also has to be taken into account. An example was tested for an organic vegetable farm, where there were beans and potatoes crops. Through a life cycle assessment, it was concluded that beans were a 92% more carbon polluting than potatoes (Adewale et al., 2016). Finally, the results have also been influenced by the method applied. Whereas the previous investigations used a processed-based method, the one applied here is the EEMRIO method, which has been reported to deliver higher impacts as it considers the entire supply chain and avoids errors associated with the defined boundaries (Junnila, 2006).

4.3. Implications of urban and peri-urban agriculture

Nowadays, urban and peri-urban agriculture is facing several challenges for their implementation mainly due to space availability, environmental constraints and lack of information and knowledge (Lin et al., 2015). Case studies analyzing the environmental impacts of these systems are required to defend the arguments claiming their numerous environmental benefits (Goldstein et al., 2016; Kontothanasis, 2017).

Through the assessment of the EF, the total impacts of the Spanish peri-urban organic orchard network were obtained. These impacts are in line with the conclusion of Kulak et al. (2013), who obtained lower impacts with urban agriculture than conventional agriculture. This author goes beyond and concludes that urban agriculture contributes to the reduction of greenhouse gases more than parks and city forests. These findings could be used as basis for urban planners to consider its implementation in cities. Furthermore, policy-makers should take advantage of the rising environmental awareness of food production among citizens, such as the increasing interest of Chinese population in organic food, and promote urban orchards as environmentally-friendly systems (Olivia and Haynes, 2017). The major concerns among citizens when implementing urban agriculture are the health and environmental risks (Huang et al., 2018). Several green labels are currently being used as means for transmitting the origin and environmental performance of products (Cai et al., 2017; Li and van't Veld, 2015). So following this concept, urban farms could also use sustainable labels including environmental information related to this topic. By showing the results of impact categories, such as human toxicity cancer effects and non-cancer effects, freshwater ecotoxicity, acidification, the marketing of their products could be improved, even more now that consumers' beliefs towards local food have positively changed (Grebitus et al., 2017).

Although sustainable food production from urban and peri-urban agriculture may be nowadays in the spotlight, this type of agriculture implies several challenges (Bryld, 2003). The risk of marginalization increases for small urban and peri-urban systems finding difficulties to access the market. This is the case observed for small organic orchards, which require the organic certification label and without it, the commercialization of their products is nearly impossible (Mutiara et al., 2017). To try to overcome this issue, building trust and communication between farmers and consumers becomes essential. Following this idea, alternative distribution channels, such as farmers' markets, are being implemented in certain countries (Polimeni et al., 2018).

4.4. Limitations

The input-output method presents some shortcomings that need to be considered. Results will contain some errors due to time-validity of the database, as the environmental extended multi-regional input-output tables are based on 2007 and our study is based in 2016. Additionally, more accurate results could be obtained if the databases were elaborated with greater sectorial and regional detail. However, depending on the impact category analyzed, a certain level of aggregation leads to small variations in the results, for example in climate change, whereas in other impact categories, such as water depletion, the results are significantly underestimated (Bouwmeester and Oosterhaven, 2013). Future efforts are being destined to improving environmental extended multi-regional input-output tables, such as the development of EXIOBASE 3 through the Desire project, which will include a time series from 1995 to 2012 and improve the environmental extensions (Stadler et al., 2016).

5. Conclusions

This study has tested the environmental performance of seven organic peri-urban orchards forming part of an organic peri-urban orchard network in Spain. The calculation of the EF has allowed the assessment of fourteen impact categories. The evaluation of the total environmental impacts and the relative impacts per unit of production revealed that the peri-urban organic orchards identified as PUO1, PUO4 and PUO6 exhibited the highest values due to a higher consumption of (1) fuel, (2) plastics and (3) electricity in comparison to the other orchards. Additionally, the direct impacts contributed significantly less than the indirect impacts, meaning that the embedded impacts along the supply chain are key factors affecting the overall environmental pressures. Through the assessment of the supply chain of this organic peri-urban orchard network, the origin of the climate change impacts was identified. The most influential countries and sectors identified were “extraction of crude petroleum” and “production of electricity by gas and coal” in Spain, China and Middle East countries. In order to design and improve peri-urban orchard networks, the EEMRIO analysis can successfully be applied to calculate the EF and serve as a guide for decision-makers to develop strategic action plans promoting sustainable cities.

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